

Exploration of Closed-loop Supply Chain Network Model Based on Mobile Wireless Communication

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With the continuous development of global resources and the increasing awareness of the need to protect the environment, remanufacturing, reverse logistics, especially the closed-loop supply chain (CLSC), has attracted extensive attention from the business community and academia. On the one hand, the CLSC can reduce energy consumption and environmental pollution, and achieve resource recycling. At the same time, it can also strengthen the competitiveness of the company to achieve the comprehensive benefits of “economy and environment”. By establishing a CLSC network model based on mobile communication technology, this paper introduces CLSC management into the mobile Internet era, and provides new ideas and methods for solving problems such as the inability to directly connect consumers and production enterprises under the traditional market transaction mode, and the inability to timely understand production progress and quality. The experimental results showed that the material value changed from 11180 to 9800 in the whole CLSC process, and the change was small after removing the normal loss. Therefore, the stability of the model could be confirmed, which effectively promoted the informatization and datalization of logistics management, and improved the enterprise operation efficiency.

Keywords: closed-loop supply chain; wireless communication; sustainable development; network model

1. INTRODUCTION

In recent years, due to the increasing awareness of environmental protection and the importance of sustainable development, countries have stipulated that manufacturers must be responsible for the recycling of waste products. At the same time, since 2003, China has also required some electronic enterprises to recycle waste products. This forms a CLSC that is different from the traditional supply chain. CLSC refers to the design and management of reverse supply chain activities that combine forward supply chain and recycling in the life cycle of products. The traditional supply chain is cost-oriented, with the goal of reducing costs and improving competitiveness. It lacks the necessary understanding of sustainable development and is a linear and unidirectional material flow structure. In the supply chain, enterprises need to invest in a great deal of manpower and material resources, and the waste generated

after consumption leads to the deterioration of the natural environment. The CLSC can benefit both the “economy and environment”, which supports the sustainable development of enterprises and society. The advantages of the CLSC over the traditional supply chain management practices means that it will become a future trend in supply chain development.

The remanufacturing of old products reduces the consumption of raw materials and environmental pollution. Hence, how to improve the efficiency of recycling has become the focus of academic and business circles. He investigated the recycling efficiency and customer behavior of CLSC, which has strong collection value, in situations where it is not convenient to collect. He analyzed the recovery efficiency of the two-level decentralized model involving manufacturers and retailers, and compared its performance with the centralized model [1]. The quality level of original equipment manufacturers not only affects their production costs, but also affects the recovery costs of independent remanufacturers. Subsequently, Wu studied the competition

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and cooperation interaction in CLSC including original equipment manufacturers and independent remanufacturers [2]. Supply chain network design is one of the important and strategic decisions that affect competitive advantage and all other decisions in supply chain management. Hajiaghahi-Keshteli established a new mixed integer nonlinear programming model, and formulated a multi-objective sustainable CLSC network design problem by considering the discount assumption in the transportation cost [3]. The security real-time data of goods transported in the supply chain needs bandwidth, and its capacity cannot be met by the current infrastructure. Therefore, mobile wireless communication technology was studied.

The Internet of Things supporting 5G in mobile edge computing aims to significantly improve this capability. To solve this problem, Jangirala designed a new and efficient RFID (Radio Frequency Identification) authentication protocol based on lightweight blockchain for the supply chain in the 5G mobile edge computing environment [4]. Health care technologies now provide accountability, quality, robustness and accuracy in disease monitoring and health care delivery plans. With the advent of mobile devices, these technologies have become more accessible and more suitable for field workers in remote areas. Rajvanshi developed a comprehensive mobile application tool, which enabled the project to carry out disease monitoring, labor management and supply chain management [5]. All these scholars introduced the construction of a supply chain model comprising wireless communication technology, but did not carry out instance testing.

In this paper, a CLSC network model was established for the purpose of reducing the system cost and, therefore, the recoverable uncertainty was considered. Following the analysis of the actual situation, a universal and representative supply chain network design model was obtained. It was determined that the average total cost of the system was reduced to the maximum under different circulation conditions. By applying the overall CLSC design pattern, a robust optimal model was established. Finally, an example was given to prove the stability of the system in practical operation, which laid the foundation for practical application.

2. SUPPLY CHAIN ALGORITHM UNDER MOBILE COMMUNICATION TECHNOLOGY

The development and application of mobile communication technology in modern society has had a great impact on human social life, and on the manufacturing industry. The continuous innovation and development of new technologies such as mobile Internet and Internet of Things have changed the traditional market transaction practices and brought about a new supply chain management mode.

With the expansion of economic globalization and the development of the information industry, the traditional product manufacturers or suppliers in the international market have gradually responded to consumer needs by delivering information on production, manufacturing, product sales and

other aspects to consumers in real time. However, with consumers' greater demand for product quality and service and the increasingly stringent requirements for environmental protection, the traditional CLSC network cannot meet the new era of consumers' demands for green, convenient, efficient and quality products [6-7]. CLSC network model research is one of the effective ways to solve the above problems. It achieves the research goal by modeling and simulating the entire CLSC system, and it is also an important supplement to and expansion of CLSC theory. Based on the development of mobile communication technology and the change of consumer demand in the new era, this paper studied the introduction of mobile communication technology into the CLSC network model, and established the CLSC network model based on mobile communication technology. By studying the information transmission methods and corresponding profits of enterprises, consumers and production enterprises under different circumstances, the study analyzed the optimal strategy of enterprises without changing the original market trading mode. Through the simulation and analysis of the changes of the relevant parameters of the model, the optimal solution was obtained and the reasons were analyzed.

2.1 Establishment Process of Equipment to Equipment (D2D) Communication

As shown in Figure 1, D2D communication has five stages: device discovery, mode selection, resource allocation, connection establishment, and data communication. Device discovery refers to mutual recognition between adjacent device terminals based on service discovery. Mode selection involves determining that the communication mode of each communication terminal is D2D or traditional cellular communication mode according to information acquisition. Resource allocation refers to the allocation of spectrum resources to terminal devices by the base station. Connection establishment refers to the establishment of a data link and radio resource control link for terminal equipment by the base station in the D2D communication mode after the equipment discovery, mode selection and resource configuration are completed. D2D communication mode is the whole process of data transmission by means of terminal devices based on D2D communication mode.

In addition, D2D communication can be divided into service discovery and device discovery, where service discovery is an arbitrary process. First, the D2D communication device can identify itself by adding an identification code after the message, which is also helpful for finding potential users who may use the D2D communication service. After that, when the D2D communication user wants to establish the D2D communication, the base station can identify the corresponding D2D user by the ID code, and transmit the configuration information discovered by the D2D to the D2D communication requester and the corresponding D2D communication user, so that the user can complete the discovery processing of the D2D device. In this way, all information in the D2D system is achieved by the continuous

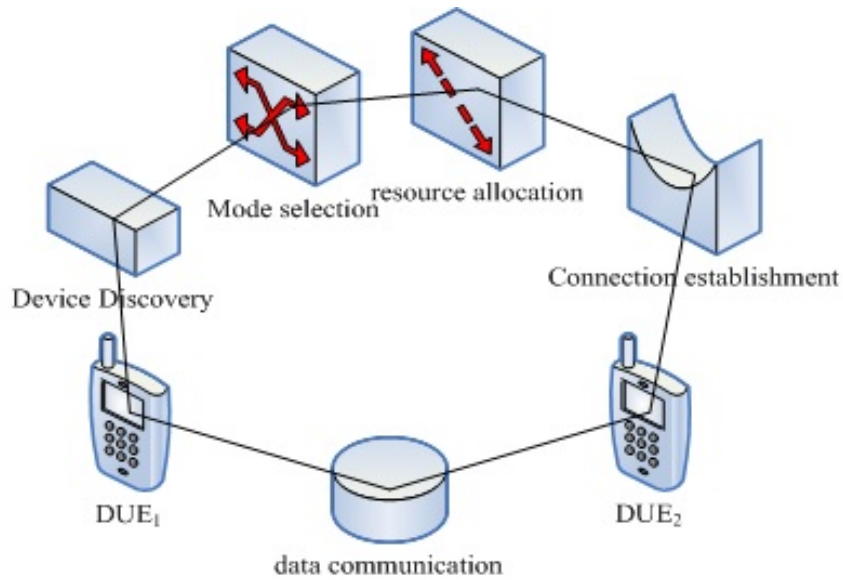


Figure 1 D2D communication establishment process.

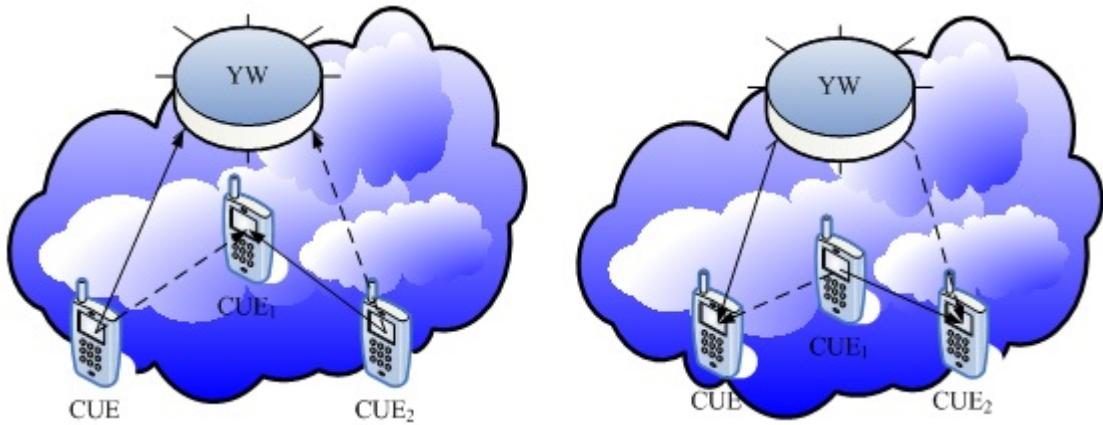


Figure 2 D2D signal interference scenario.

interaction between the D2D candidate equipment and the base station.

2.2 Radio Resource Management of D2D Communication

D2D users can use the spectrum resources in the cellular network, and use time division duplex (TDD) and frequency division duplex (FDD) for D2D communication. D2D communication can be achieved through uplink (UL), downlink (DL), uplink and downlink, etc. In D2D communication, the upstream spectrum resources of D2D users are the focus of current research. This is because the interference problem of the uplink is much simpler than that of the downlink, as shown in Figure 2. In the case of downlink interference, the cellular user equipment (CUE) of D2D communication is the victim of interference. However, in the case of uplink interference, the largest victim of D2D communication interference is the base station, while the CUE is not affected by the interference. Therefore, regarding the interference

problems arising from the coexistence of D2D and cellular communication, it does not cause interference to mobile users when there is uplink interference, but it affects the performance of mobile phones in the case of downlink interference due to the interference of D2D users.

2.3 Interference of D2D Communication

Interference is an important issue in D2D communication, which can have a significant impact on D2D communication. At the same time, when D2D communication is seriously interfered with by cellular communication, D2D communication has a great impact on the improvement of system performance.

In UL, CUE transmits data to the base station (YW). DUE₁ and DUE₃ transmit data to DUE₂ and DUE₄ respectively. In this process, base station YW interferes with DUE₁ and DUE₃ respectively. The interference to YW can be expressed by Formula (1):

$$\varphi_{YW} = Q_{T_1} * H_{T_1,YW} + Q_{T_3} * H_{T_3,YW} \quad (1)$$

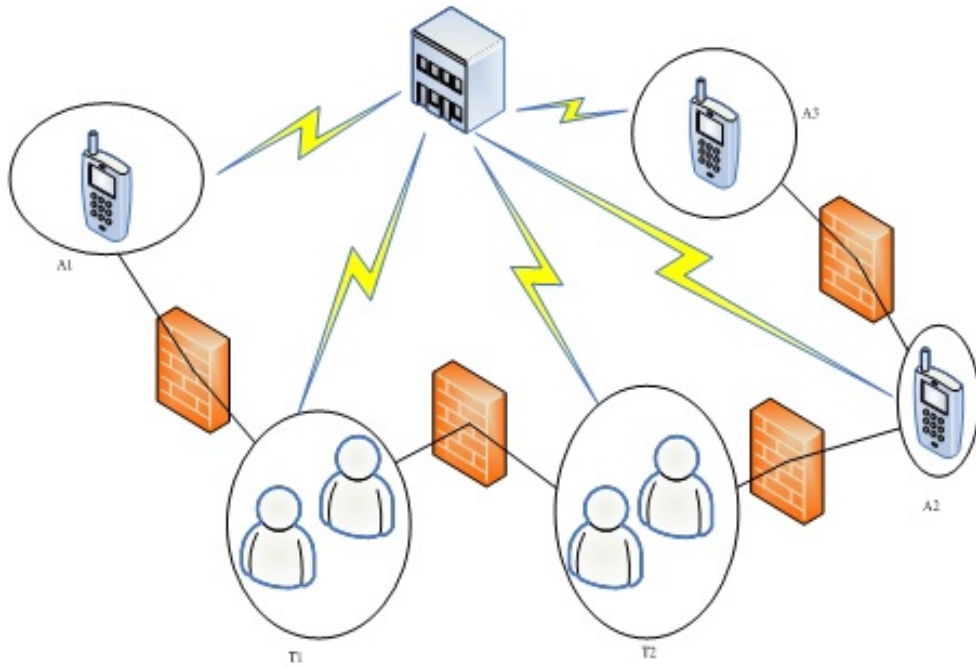


Figure 3 Cell system model.

Among them, Q_{T_1} represents the transmission power of DUE₁, and $H_{T_1,YW}$ represents the channel gain between DUE₁ and YW.

In DL, CUE transfers data to YW. DUE₂ and DUE₃ transmit data to DUE₁ and DUE₄ respectively. In this process, CUE interferes with DUE₁ and DUE₃ respectively. The interference to CUE can be expressed by Formula (2):

$$\varphi_{CUE} = Q_{T_2} * H_{T_2,C} + Q_{T_3} * H_{T_3,C} \quad (2)$$

Among them, $H_{T_2,C}$ represents the channel gain between DUE₂ and CUE.

2.4 D2D Communication Spectrum Resource Allocation Algorithm

The system mode studied in this paper is a single-cell scenario with one group of base stations, multiple groups of cells and multiple groups of D2Ds. D2D and mobile phones are evenly distributed in the cell. D2D users use the downlink resources shared by the mode. Mobile phone users utilize the spectrum resources of orthogonal frequency division multiple access technology. In addition, all users in the unit are equipped with an omnidirectional antenna. The base station knows not only the geographic coordinates of users, but also the channel status of all users' communication links in the entire cell. There are two types of communication links: a conventional cellular communication link and a D2D communication link. The unit system model is shown in Figure 3.

In this system mode, the base station is represented as YW; cellular users are represented as A1, A2, A3, and D2D users are represented as T1, T2. T_1^D and T_1^K represent the sending and receiving of T1.

In this model, only the mutual interference between the elements needs to be considered. According to the interference mode provided by the Radio Communication Commission of the International Telecommunication Union, the channel gain between the base station and the cellular user, between the base station and the D2D user and the receiving end, and between the D2D user and the transmitting end and the cellular user can be calculated, which are respectively:

$$H_{Y,C_j} = 10^{-Q_{O_{Y,C_j}}/10} \quad (3)$$

$$H_{Y,T_i^K} = 10^{-Q_{O_{Y,C_i^K}}/10} \quad (4)$$

$$H_{T_i^D,C_i^K} = R_{T_i^D,C_i^K} * O_{T_i^D,C_i^K}^{-\beta} \quad (5)$$

$$H_{T_i^D,C_j} = R_{T_i^D,C_j} * O_{T_i^D,C_j}^{-\beta} \quad (6)$$

Among them, $Q_{O_{Y,C_j}}$ and $Q_{O_{Y,C_i^K}}$ represent the macro channel loss between the base station and mobile users, and between the base station and D2D users and the receiver; $R_{T_i^D,C_i^K}$ and $R_{T_i^D,C_j}$ represent standardization constants. $O_{T_i^D,C_i^K}$ and $O_{T_i^D,C_j}$ respectively represent the distance between the D2D user and the transmitting end and the receiving end, and the distance between the D2D user and the transmitting end and the cellular user.

2.5 Construction of a Closed-Loop Supply Chain Management Network Model

In recent years, with the rapid development of the social economy, the natural environment has been greatly damaged, which poses a great threat to human survival and development. The traditional supply chain aims to reduce costs

and improve its competitiveness. However, the enterprises in the supply chain nodes with economic interests as the core would also cause certain pollution to the environment after consuming a lot of resources, thus forming a linear and one-way structure, which obviously does not support sustainable development. Due to the economic development, the traditional supply chain development model needs to be changed. Under the original single supply chain system, multiple links such as recycling, reprocessing, redistribution, detection/screening, and scrapping can be improved to organically combine the traditional forward supply chain with various reverse activities, thus forming a closed-loop system, in which all materials are circulated. At the same time, it can effectively manage products and reduce the negative impact of a series of supply chain behaviors on the environment, which is called CLSC [8-9]. The formation of CLSC stems from the shortage of resources, the worsening environment and the constraints of relevant laws and regulations [10-11].

A closed-loop supply chain refers to the process of recycling and reusing waste items and materials, consisting of logistics, information, capital, energy, and other elements. The closed-loop supply chain management network model involves the modeling of this supply chain management approach to achieve optimized management and maximum efficiency.

The establishment of a closed-loop supply chain management network model involves the following *Establish a framework structure for the supply chain*

Firstly, it is necessary to define the boundaries and scope of the closed-loop supply chain and establish a framework structure for the supply chain. This structure should include the roles and relationships of suppliers, producers, distributors, retailers, recyclers, and other links in the supply chain, as well as the corresponding logistics, information, capital, and energy flows.

Determine evaluation indicators and weights

Secondly, it is necessary to determine the indicators and weights for evaluating closed-loop supply chain management. Common indicators include cost, efficiency, environmental impact, etc., and the importance of different indicators varies. By quantifying and normalizing indicators, data support can be provided for subsequent model establishment.

Establish a closed-loop supply chain management network model

Next, a closed-loop supply chain management network model needs to be established. The model should include factors such as decision variables, constraint conditions, and objective functions for each stage of the supply chain. Decision variables include order quantity, production quantity, inventory quantity, recycling quantity, etc. The constraints include production capacity, inventory limit, recycling capacity, etc. The objective function can be cost minimization, efficiency maximization, or environmental impact minimization.

Optimize model parameters and algorithms

After establishing the model, it is necessary to optimize the model parameters and algorithms to improve the accuracy and efficiency of the model. Common optimization algorithms include linear programming, Integer programming, dynamic programming, genetic algorithm, etc. By selecting appropriate algorithms and adjusting parameters, the model

can more accurately reflect the actual situation of the closed-loop supply chain and achieve optimal management.

Implement a closed-loop supply chain management network model

Finally, it is necessary to apply the established closed-loop supply chain management network model to actual supply chain management. Through data collection, analysis, and feedback mechanisms, models can be continuously optimized and improved to achieve sustainable development of closed-loop supply chains.

In summary, establishing a closed-loop supply chain management network model is the key to achieving optimized management and maximizing benefits. By establishing accurate and efficient models, various challenges and problems faced in closed-loop supply chain management can be effectively addressed, improving the quality and efficiency of the supply chain, and achieving sustainable development.

Through recycling, splitting, recycling and reprocessing, the enterprise has achieved recycling, bringing huge social and economic benefits to the enterprise. Therefore, the traditional forward supply chain and reverse supply chain must be combined to achieve a new management mode that goes beyond the traditional one. The CLSC management mode is a new approach that conforms to this historical change [12-13]. CLSC system is a combination of traditional forward supply chain and reverse logistics, and its business scope is far beyond the traditional supply chain system. However, it is not simply “forward+reverse”; it includes many changes from the strategic level to the enterprise operation level, which are much more complex and difficult than the traditional forward supply chain. The goal of CLSC management is to realize the overall interests of “economy and environment”, which is not only conducive to the sustainable development of enterprises, but also helps to ensure the sustainable development of the whole society [14-15]. CLSC has strong advantages and is an important direction of China’s supply chain development in the future.

2.6 CLSC Model of Mobile Wireless Communication

With the development of global economic integration and network economy, the competition among enterprises is becoming increasingly fierce. Enterprises can no longer adapt to the rapid development of the market by relying solely on their own capabilities. They must strengthen their competitiveness by improving their overall capabilities. In supply chain management, the supplier’s inventory management can effectively overcome the demand amplification effect and reduce the supply chain cost, thus improving the capacity of the supply chain. However, due to the application of supplier inventory theory in practice, its shortcomings are becoming more and more obvious; that is, the logistics capability of suppliers cannot fully play its role, and sometimes it plays a negative role, thus damaging their own profits. In the case of mobile wireless communication technology, the CLSC mode can effectively use its own logistics capabilities to make up for suppliers’ deficiencies in inventory management,

and can give full play to its own advantages, thus effectively improving the overall level of the entire supply chain system [16]. Therefore, CLSC management theory has been given great importance and studied by many scholars, although it is still in its infancy and subject to ongoing discussion and research.

With the continuous development of mobile communication technology in modern society, an increasing number of enterprises use mobile communication networks to achieve real-time information about their product demand. Technological research on new methods and theories has seen the emergence of technologies including the Internet, the Internet of Things, and big data analysis. These IT fields have the characteristics of being small scale, requiring less investment, and producing quick results etc., so they can be quickly applied in traditional industries. Among them, wireless Internet is low cost, and rapidly transmit information via a network. Wireless Internet comprises a wireless local area network, mobile devices, satellite communication facilities, etc. Together, these networks constitute a seamless wireless broadband communication system, namely wireless Internet. With the increasing integration of information technology within the manufacturing industry, real-time processing and analysis of information stored in smart phones can provide a more valuable reference for supply chain management. In this paper, the CLSC network model based on a mobile communication network was established in order to better study related problems and provide corresponding solutions.

3. CLSC NETWORK DESIGN MODEL

3.1 Description of Assumptions

In order to simplify the model, the following assumptions are made for the model: the model considers only the case of single cycle and single product; in terms of cost, only the fixed construction cost, product related cost and transportation cost of the equipment point are considered, and the construction period cost is not considered; the transportation costs of enterprises at different facilities are fixed, and different transportation modes are not considered; second hand products, materials and parts processed by the recycling center shall be preferentially entered into distributors, manufacturing and remanufacturing enterprises, and only the transportation costs are taken into account; the quality of the newly produced product is the same as that of the new product, and it can also meet the needs of customers in the same market; the carrying capacity of each facility point and the carrying limit of each transport line are known, while the recovery center does not take into account its equipment capacity and other related factors.

3.2 Model Construction

The network structure model of CLSC aims to minimize the total cost of the supply chain system in a single operation period. The purpose of this model is to establish the fixed

cost of the equipment (X), the cost of the product itself (Y), and the transportation cost (Z).

The costs are:

The fixed cost X of facility construction is:

$$X = \sum_{j \in J} g_j B_j + \sum_{j \in J} g_i B_i + \sum_{m \in M} g_m B_m \quad (7)$$

Each item in Formula (7) represents the fixed construction cost of manufacturing center, distribution center and waste center respectively.

The cost Y of the product itself is:

$$Y = \sum_{i \in I} E_{ni} \cdot A_{ni}^w + \sum_{j \in J} E_{nj} \cdot A_{ni}^w + \sum_{i \in I} E_{nm} \cdot A_{nm}^w \\ + \sum_{o \in O} \sum_{j \in J} E_{linew} \cdot A_{linew}^w + \sum_{o \in O} \sum_{j \in J} E_{inew} \cdot A_{inew}^w \quad (8)$$

Among them, the first, second and third items represent the cost of recycling and reprocessing; the fourth item represents the cost of raw materials purchased by manufacturing center j from supplier o , and the fifth item represents the cost of new products manufactured by manufacturing center j .

The transportation cost Z is:

$$Z = \sum_{o \in O} \sum_{j \in J} A_{oj}^w \cdot g_{ol} \cdot u_g + \sum_{j \in J} \sum_{i \in I} A_{ji}^w \cdot g_{ji} \cdot u_g \\ + \sum_{n \in N} \sum_{j \in J} A_{nj}^w \cdot g_{nj} \cdot u_g \\ + \sum_{n \in N} \sum_{i \in I} A_{ni}^w \cdot g_{ni} \cdot u_g + \sum_{n \in N} \sum_{m \in M} A_{nm}^w \cdot g_{nm} \cdot u_g \quad (9)$$

Each item in Formula (9) is the transportation cost from supplier o to manufacturing center j , manufacturing center j to distribution center i , recycling center n to manufacturing center j , recycling center n to distribution center i , and recycling center n to scrap center m .

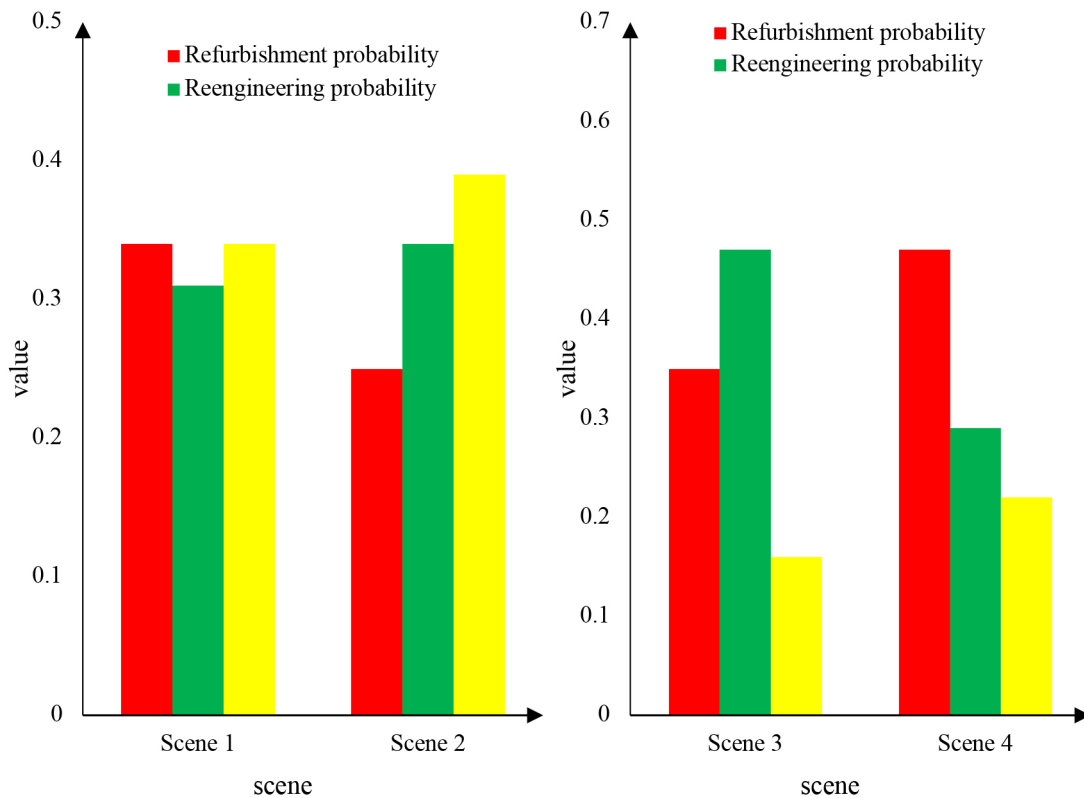
3.3 Example Problem Description

To meet the needs of national energy conservation and emission reduction, a small household appliance company established a closed-loop recycling supply chain system during the production process to achieve the purpose of recycling. The company takes the recycled products as the center and performs the functions of detection, classification, reprocessing, etc. After that, the processed raw materials, spare parts and waste materials that have lost their reuse value are remanufactured, resold and disposed of in an environmentally friendly manner by the node enterprises.

According to the product characteristics of the enterprise, its service life is assumed to be 12 years; that is, the recovery rate of products is different in different life cycles. In Table 1, it is assumed that all recycled products are in the life cycle. According to the initial estimate, the four situations would occur in the recycling center.

Table 1 Data statistics of the recycling center under various scenarios.

	Scene 1	Scene 2	Scene 3	Scene 4
Probability of scenario occurrence	25%	25%	25%	25%
Product recovery	3800	3500	3200	3400
Life span of recycled products	2-11	2-9	3-9	4-11
Demand	5800	5500	6200	6000

**Figure 4** Related parameters of waste products in the recycling center. (a) Related parameters of waste products in scenarios 1 and 2. (b) Related parameters of waste products in scenarios 3 and 4.**Table 2** Capacity limits and fixed construction costs of alternative facility points.

Project		Manufacturing Center	Distribution Center	Abandonment center
Facility Capacity Limits	1	6000	7000	8500
	2	5000	8000	8000
Fixed construction cost of facilities	1	400000	500000	500000
	2	300000	450000	550000

According to the requirements of the enterprise itself, and according to the above treatment methods for the quality uncertainty of recycled products, the quality index of waste products and the repair probability, reconstruction probability and waste disposal probability of waste products can be calculated, as shown in Figure 4.

Figure 4 (a) shows the relevant parameters of waste products in scenarios 1 and 2, and Figure 4 (b) shows the relevant parameters of waste products in scenarios 3 and 4. Through calculation, it can be seen that in Scene 4, the renovation probability was the highest, 0.47, while the reconstruction probability was the lowest, 0.29; the lowest abandonment probability of 0.16 was reflected in scenario 3. After preliminary investigation and analysis, two production/reproduction manufacturers, two distribution

centers, two scrapping centers and two distribution centers were determined. The specific information of each address is shown in Table 2. Each transportation cost of products/materials during transportation was 50 (yuan/kg.km), which depended on the characteristics of products (as shown in Table 2).

3.4 Case Optimization Results and Evaluation

In the above variable results, $\alpha_2=1$ means that for the first recycling scenario, place 2 is taken as the production center. From the logistics volume of o-j and the path (1,2)=3160kg, it can be seen that the new raw material flow from the raw

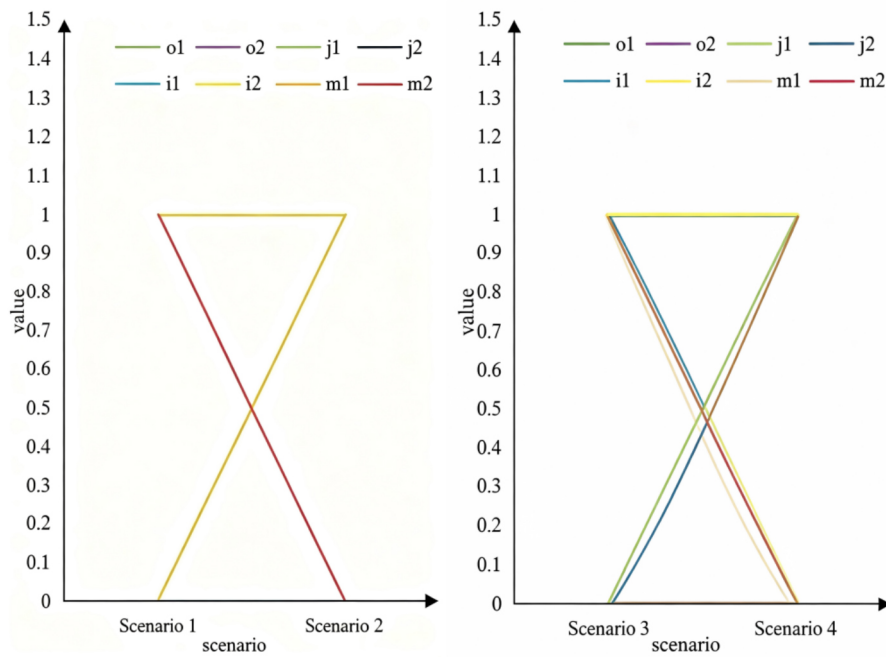


Figure 5 Site selection results of supply chain network facilities. (a) Site selection results of network facilities for scenarios 1 and 2. (b) Site selection results of network facilities for scenarios 3 and 4.

Table 3 Flow between CLSC facility points.

Project	o-j		j-i		n-j		n-m	
	Route	Logistics volume	Route	Logistics volume	Route	Logistics volume	Route	Logistics volume
1	(1,2)	3160	(2,2)	4370	(1,2)	1210	(1,2)	1390
2	(1,2)	2700	(2,2)	4100	(2,1)	1210	(1,2)	980
3	(2,1)	160	(1,2)	160	(2,1)	1400	(2,2)	1100
	(2,2)	3110	(2,2)	4500				
4	(2,2)	2400	(2,2)	4300	(1,2)	1000	(2,2)	1500

material supplier 1 to the production center 2 is 3160kg. According to the above results, the logistics flow and location distribution among the equipment points in CLSC are shown in Figure 5 and Table 3 respectively.

Figure 5 (a) shows the result of network facility location in scenarios 1 and 2, and Figure 5 (b) shows the result of network facility location in scenarios 3 and 4. Under different conditions, the position of CLSC changes little, while the recovery and quality does not change significantly. Through comparison, the location of CLSC network was determined: o2 – j2 – i2 – recycling center – m1.

It can be seen from Table 3 that the layout of a closed-loop feeding network is: o2 – j2 – i2 – recovery center – m1, in these different recovery situations. The logistics volume and relative differences between equipment are shown in Figure 6.

Figure 6 (a) shows the logistics volume from recycling center to waste, distribution center and manufacturing center under different scenarios, and Figure 6 (b) shows the logistics volume from suppliers to manufacturing center and from manufacturing center to distribution center under different scenarios. Under different recycling conditions, the number of suppliers, manufacturing, distribution, or logistics in the recycling process has not changed significantly. In Scene

1, the recovery process changed from 11180 to 11080 and then to 9800. After the waste materials were removed, the change is very small. The change from 11080 to 10600 and then to 10000 in Scene 2 shows that the operation strategy of the CLSC system was stable. These results show that the proposed optimal model of the CLSC system is feasible and robust. The CLSC network built by this model can keep the system running stably under uncertain conditions.

4. CONCLUSIONS

The “cycle” advocated by CLSC not only can bring economic benefits to enterprises, but also promotes the protection of the ecological environment. Therefore, the implementation of CLSC plays an important role in the sustainable development of society, economy and the natural environment. However, due to the complexity of CLSC itself and changing market conditions, there are great risks in the construction and application of the CLSC system. In the network design and optimization of the CLSC system, it is necessary to deal with the negative impact of existing or potential uncertainties, so that it can achieve long-term and stable development in terms of operation and management. By analysing the existing

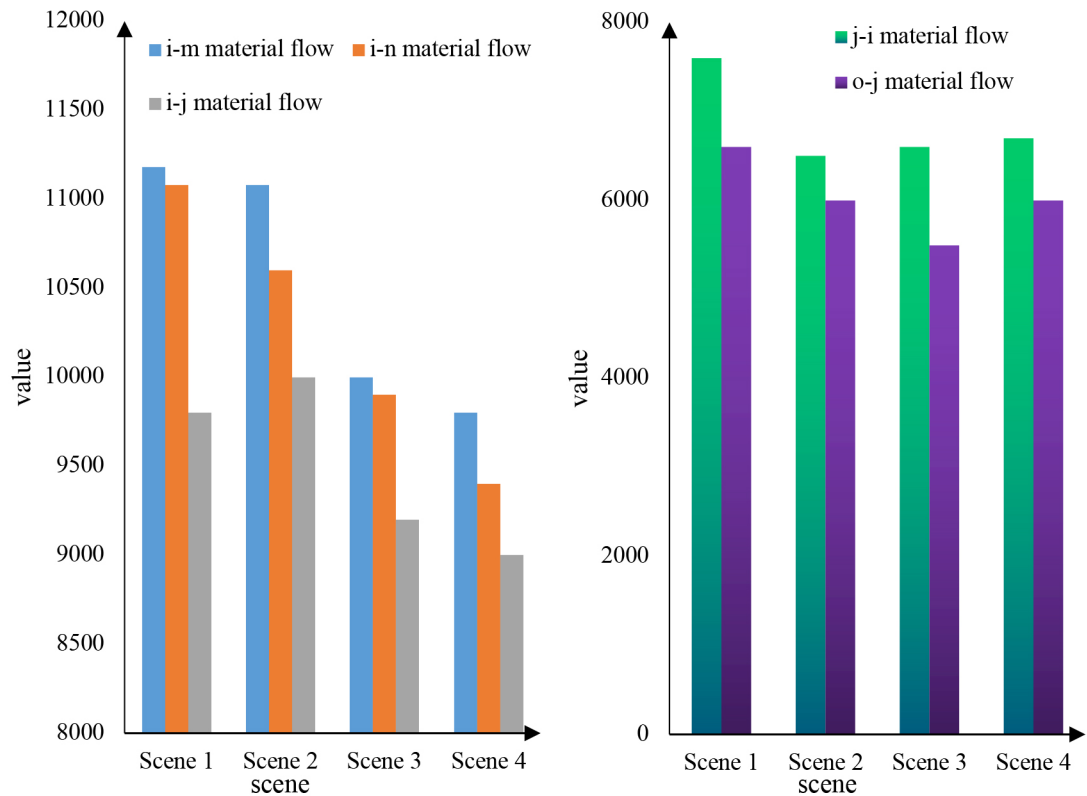


Figure 6 Comparison of CLSC operation strategies under different scenarios. (a) Logistics volume from recycling center to waste, distribution center and manufacturing center under different scenarios. (b) Logistics volume from suppliers to manufacturing center and from manufacturing center to distribution center under different scenarios.

research results, combined with the content of the paper, the main research contents of this paper were summarized: on the basis of CLSC, a CLSC network model was constructed with two uncertain factors considered and the goal of minimizing the system; the robust optimization model of CLSC network was established by using the robust optimization theory, and the model was verified by an example.

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